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RESEARCH OPPORTUNITIES IN HUMAN BEHAVIOR AND PERFORMANCE

January 1985

Prepared for

THE LIFE SCIENCES DIVISION
OFFICE OF SPACE SCIENCE AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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FOR EXPERIMENTAL BIOLOGY
9650 Rockville Pike
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Edited by
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FOREWORD

The Life Sciences Research Office (LSRO), Federation of American Societies for Experimental Biology (FASEB), provides scientific assessments of topics in the biomedical sciences. Reports are based upon comprehensive literature reviews and the scientific opinions of knowledgeable investigators engaged in work in specific areas of biology and medicine.

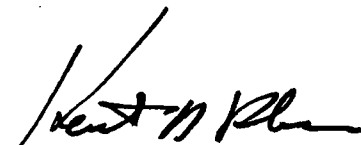
This technical report was developed for the National Aeronautics and Space Administration (NASA) in accordance with the provisions of Contract Number NASW 3924. It was prepared and edited by Julien M. Christensen, Ph.D., Chief Scientist, Universal Energy Systems, Dayton, Ohio, and John M. Talbot, M.D., Senior Medical Consultant, LSRO.

The LSRO acknowledges the contributions of the investigators and consultants who assisted with this study. The report reflects the opinions expressed by an ad hoc working group that met at the Federation on August 6-8, 1984. The study participants reviewed a draft of the report and their various viewpoints were incorporated into the final report. The study participants and LSRO accept responsibility for the accuracy of the report; however, the listing of these individuals in Section VII does not imply that they specifically endorse each study conclusion.

The report was reviewed and approved by the LSRO Advisory Committee (which consists of representatives of each constituent Society of FASEB) under authority delegated by the Executive Committee of the Federation Board. Upon completion of these review procedures, the report was approved and transmitted to NASA by the Executive Director, FASEB.

While this is a report of the Federation of American Societies for Experimental Biology, it does not necessarily reflect the opinion of each individual member of the FASEB constituent Societies.

January 25, 1985
(date)


Kenneth D. Fisher, Ph.D.
Director
Life Sciences Research Office

SUMMARY

The NASA research program in the biological and medical aspects of space flight includes investigations of human behavior and performance. The research focuses on psychological and psychophysiological responses to operational and environmental stresses and demands of space flight, and encompasses problems in perception, cognition, motivation, psychological stability, small group dynamics, and performance. The primary objective is to acquire the knowledge and methodology to aid in achieving high productivity and essential psychological support of space- and groundcrews in the Space Shuttle and space station programs.

As a part of the process of research program evaluation, NASA requested that the Life Sciences Research Office (LSRO) of the Federation of American Societies for Experimental Biology review its program in psychology and identify research for future program planning. This report is based upon the opinions and suggestions of an ad hoc Working Group of expert behavioral scientists whose names are listed in section VII.

Crew motivation and effectiveness have been high in NASA's manned missions, and overt functional impairment caused by adverse psychological responses has not been reported. However, some experts believe that longer, increasingly complex, and relatively routine space missions involving larger, heterogeneous crews may generate psychological and psychosocial problems for which solutions are not currently available. In the planned space station, potentially stressful factors include physical and social isolation, confinement, boredom, threat of potential hazards, and discomfort associated with crowding, lack of privacy, artificial life support, and microgravity.

Documented untoward psychological and psychophysiological responses to space flight include transient disorientation and spatial illusions, temporary alteration of visual function, as well as degradation of performance and sleep disturbance associated with undue shifts in work, rest, and sleep schedules. Space sickness, which compromises crew effectiveness, may have a significant psychological component in some people.

Anecdotal information from space missions of the United States and Soviet Union includes other examples of adverse psychological effects such as hostility between space- and groundcrews, friction between members of spacecrews, and episodes of mental depression. Past activities of an operational or research nature that are analogous to space missions in terms of such factors as

confinement, physical and social isolation, crowding, lack of privacy, and perceived danger, include long submarine missions, undersea habitats, and polar stations. Research and operational monitoring have shown that adverse psychological effects in these endeavors have ranged from listlessness and depression through anxiety with psychosomatic symptoms, sleep disturbance, and fatigue, to irritability and frank hostility. Evidence for decreased psychomotor performance in certain undersea activities has been documented.

Among the unresolved problems of long-term human occupancy of a space station are questions of optimal psychological and psychophysiological criteria and methods for crew selection and assignment, psychological and psychosocial factors in crew compatibility, motivation, and productivity, and the effects of the space station environment on perceptual, intellectual, and motor skills. The members of the LSRO ad hoc Working Group examined NASA's current research program in psychology, heard presentations on the space station, and focused their deliberations on such key topics as cognition, perceptual-motor function, performance assessment, psychological stability, motivation, psychosocial aspects, methodology, and models. In the opinion of the Working Group, NASA's current research program in psychology includes some worthwhile investigations whose results may ultimately prove applicable to problems of manned space flight; however, the programmatic level of effort is insufficient to produce the data needed to satisfy the program objectives. Therefore, the ad hoc Group reiterated the recurring opinion of past scientific advisory groups that NASA would benefit greatly in both short and long terms by planning and implementing a comprehensive, well-integrated research program in psychology including basic and applied research and participation by behavioral scientists in space station planning, crew selection and training, missions simulations, and actual missions of the space station. Suggested research and methodology as well as certain technical considerations are specified in Section V.

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I. INTRODUCTION

The Biomedical Research Program of the National Aeronautics and Space Administration (NASA) addresses problems associated with manned space flight. Part of the program concerns the psychological aspects of space flight, representing a broad field of topics. This report on the psychological aspects of space flight is based upon the opinions and suggestions of an ad hoc Working Group of prominent behavioral scientists (see Section VII), whose members met at the Federation on August 6-8, 1984 and who contributed additional data and refinements to the report in the subsequent months.

NASA's manned space missions have involved flights of short (hours or days) to medium (weeks to <3 mo) duration, usually with crews of up to three astronauts. In the current Space Shuttle Program, missions nominally last for 7-10 d, with crews of four to eight members. Crew motivation, productivity, and effectiveness have been high in all of NASA's manned missions, and overt functional impairment based on adverse psychological responses has not been reported (Berry, 1973, 1974; Johnston and Dietlein, 1977; Nicogossian and Parker, 1982). However, some experts suggest that longer, increasingly complex, but more nearly routine space endeavors such as the Soviet Salyut missions and the planned United States space station may produce psychological problems whose solutions are not currently at hand (Brady, 1983; Gurovskiy and Novikov, 1981; Leonov and Lebedev, 1973; Montemerlo and Cron, 1982; Simonov, 1975). Moreover, anecdotal information suggests that, in some of the Shuttle missions, phenomena of a psychophysiological and perceptual nature have occurred that are poorly understood and whose operational significance needs careful definition.

The ultimate configuration of the space station has not been decided. However, as currently conceived, it will consist of several modules designed to accommodate a crew of three to five persons initially, and eight to twelve ultimately, in nominal missions lasting 90 d and operating in a low Earth orbit (500 km). It will be supported logistically by the Shuttle Orbiter of the Space Transportation System (STS).

In view of the comparatively limited experience in terms of numbers of participants in long-term (arbitrarily described here as >30 d) space missions in the programs of the United States and the Soviet Union, reliable predictive data are not available on the likelihood of significant performance degradation from possible adverse behavioral effects of long-term occupancy of a space station by multiple crew members.

Several factors in the environment of a space station may become psychologically stressful as mission duration extends from days to weeks to months. Examples of such factors are physical isolation, social deprivation, confinement, a constant potential for the occurrence of hazardous incidents, and discomfort associated with crowding, lack of privacy, artificial life support, and weightlessness. No reports are available suggesting that such conditions have compromised crew performance in American space missions. However, numerous reports from somewhat analogous types of missions document certain adverse psychological and psychophysiological responses of some of the participants: medium and long submarine missions (Earls, 1969; Serxner, 1968; Tansey et al., 1979; Weybrew, 1957); undersea habitats (Deutsch, 1971; Helmreich, 1973; Radloff and Helmreich, 1968); polar stations (Gunderson, 1968); and long-term (e.g., 6 mo) Soviet manned space missions (Bluth, 1981; Gurovskiy and Novikov, 1981; Petrov et al., 1979; Simonov, 1975; Vinograd, 1974).

Adverse effects in these primarily operational experiences ranged from listlessness and depression through heightened anxiety with psychosomatic symptoms, sleep disturbance, and fatigue, to irritability, hostility, and deterioration of personality. The potential for impairment of performance associated with such responses appears obvious. In a laboratory setting, however, ground-based studies of confined, physically isolated subjects for periods up to 30 d have not demonstrated consistent untoward effects on cognitive function and skilled performance (Chiles et al., 1968; Smith, 1969; Zubek, 1969). Moreover, while behavioral aberrations have been observed in divers living in undersea habitats, such as development of hostility toward topside personnel in Project Tektite I (Deutsch, 1971), sleep disturbances, and diminished psychomotor performance on the more complex tests in Project Sealab II (Miller et al., 1967), adverse behavioral responses in the Sealab and Tektite series were minimal and apparently did not significantly compromise planned mission achievements.

Among the unresolved problems concerning the human components of the space station system are questions of optimal psychological and psychophysiological criteria and methods for crew selection, psychological and psychosocial factors in crew compatibility and productivity, and the effects of the space station environment on perceptual, intellectual, and motor skills. Numerous other pertinent questions are suggested by the list of topics in Table 1. Some of the topics may appear more appropriate to NASA's Human Factors Program, which is aimed at optimizing space station habitability and the interfaces between the human operator and his equipment, machines, and total system. The Human Factors Program is outside the scope of this study. However, a great deal of basic research is still needed to provide an adequate data base for human factors applications in terms of perceptual, cognitive

and psychomotor processes, capabilities, and limitations in relation to spacecraft and space systems.

To achieve its objectives in the manned space programs, NASA's policies concerning operational personnel require that the best qualified individuals be selected, that the most effective educational and training methods be used to develop and maintain necessary skills, and that tested methods of preventing or ameliorating the untoward biological effects of space flight be employed to promote physical and mental well-being and maximum operational effectiveness. NASA conducts a research program in the psychological aspects of manned space flight in order to support its space missions and its personnel policies. The program seeks to expand the data base on the psychological responses to operational and environmental stresses of the proposed space station, develop methodology for identifying stress-susceptible individuals and for nonintrusive measurement of psychological problems and performance decrements in mission personnel, and to develop measures for preventing or controlling space-related psychological and performance impairment. An associated program objective is development of a model relating stress, psychological well-being, and task performance.

As a part of the ongoing effort to review and evaluate its research program in the life sciences, NASA requested that the Life Sciences Research Office of the Federation of American Societies for Experimental Biology undertake a review of its research program in psychology.

Table 1. Some factors that influence behavior and performance of spacecrew and other operational personnel

<u>A. Psychological, Psychosocial, and Psychophysiological</u>	<u>B. Environmental</u>	<u>C. Space System</u>	<u>D. Support Measures</u>
limits of performance (perceptual, motor)	spacecraft habitability	mission duration and complexity	inflight psychosocial support
cognitive abilities	confinement	organization for command and control	recreation
decision-making	physical isolation	division of work, man/machine	exercise
motivation	social isolation	crew performance requirements	selection criteria
adaptability	weightlessness	information load	work-rest/avoiding excess workloads
leadership	lack of privacy	task load/speed	job rotation
productivity	artificial life support	crew composition	job enrichment
emotions/moods	noise	spacecrew autonomy	preflight environmental adaptation training
attitudes	work-rest cycles	physical comfort/quality of life	social sensitivity training
fatigue (physical and mental)	shift changes	communications (intracrew and space-ground)	training for team effort
crew composition	desynchronization	competency requirements	inflight maintenance of proficiency
crew compatibility	simultaneous and/or sequential multiple stresses	time compression	cross training
psychological stability	hazards		recognition, awards, benefits
personality variables	boredom		ground contacts
social skills			self-control training
human reliability (error rate)			
space adaptation syndrome			
spatial illusions			
time compression			

II. OBJECTIVES AND SCOPE OF THE STUDY

The objectives of the LSRO study of the psychological aspects of manned space flight are to:

1. review extant information on the subject;
2. examine NASA's psychology research program;
3. identify significant gaps in knowledge;
4. formulate suggestions for future research program planning;
5. produce a documented report of the foregoing items that can be used for program planning.

In accordance with NASA's guidance, the report focuses on issues of human behavior and performance related to the contemplated United States Space Station, to the Shuttle Program, and to both near- and long-term, space-related problems of a generic nature in applicable disciplines of psychology.

Members of the LSRO ad hoc Working Group on Behavior and Performance heard presentations by NASA program managers and principal investigators and reviewed the scientific literature, unpublished information from the United States and Soviet space programs, and NASA's program documents for the research program in psychology. In broad terms, the ad hoc Working Group focused its discussions on: (1) human performance requirements for the long-term (90 d) manned mission; (2) human perceptual, cognitive, and motor capabilities and limitations in space; (3) crew composition, individual competencies, crew competencies, selection criteria, and special training; (4) environmental factors influencing behavior; (5) psychosocial aspects of multi-person space crews in long-term missions; (6) career determinants in NASA; (7) investigational methodology and equipment; and (8) psychological support.

III. BACKGROUND INFORMATION

A. EXPERIENCE FROM SPACE FLIGHT

1. Documented Information

Most of the published accounts of manned space missions suggest that, with few exceptions, the perceptual, cognitive, and psychomotor performance of the crews was apparently unimpaired in terms of mission completion (Gazenko et al., 1981; Johnston et al., 1975; Johnston and Dietlein, 1977; Nicogossian and Parker, 1982). Individual exceptions to maintaining adequate performance and psychological well-being during space flight have been caused in some cases by space sickness (part of the "space adaptation syndrome") (Homick and Miller, 1975; Homick, 1979; Johnson, 1984), transient disorientation and spatial illusions in a few cases (Yuganov and Kopanov, 1975), and, in nearly all flights initial slowness in accomplishing tasks (or a reduced work efficiency) and diminished motor coordination and precision of movement during the adaptation to weightlessness. However, the crew members adjust rapidly to the weightless environment and become proficient in developing techniques to optimize task performance. Thus, the initial disturbances of motor function have not been considered critical (Pestov and Geratewohl, 1975). However, postflight motor dysfunction can be rather debilitating for days or weeks.

When work, rest, and sleep schedules were shifted from a 24-h day set to local time of the launch site during the Soyuz program, cosmonauts experienced some degradation of performance and disturbed sleep (Leonov and Lebedev, 1973; Leonov, 1979). Sleep loss, poor quality sleep, and fatigue were reported from the Gemini IV, Apollo 7, 8, 13, 14, 15, and STS-1 missions (Berry, 1970; Goldwater, 1981; Strughold and Hale, 1975). In Apollo mission 7, the sleep periods of the three astronauts were staggered so that one crew member could always be on watch. In Apollo 8, operational demands required sleep schedules that were quite different from preflight practice. In neither mission was sleep judged to be adequate. In Apollo 9, the quality of sleep improved when the astronauts slept simultaneously during their accustomed terrestrial hours (Strughold and Hale, 1975). During lunar surface periods in the Apollo Program sleep was generally inadequate. Space flight experience suggests that, at least for near-Earth missions, sleep periods should be synchronous with customary bed times at the launch site.

Two Russian cosmonauts observed deterioration of the accuracy of their "standard" movements during the first few days of orbital flight in the Soyuz-9 spacecraft; motor responses frequently exceeded nominal levels for a given movement (Beregovoy,

1979). Beregovoy (1979) reported a sensation of slow movement of the hand while writing in weightlessness, apparently another transient illusion of space flight involving alteration of time sense. At the time of entering the weightless state it is fairly common to experience illusory sensations such as overturning or inversion of the body, or apparent movement of objects within the visual field. These false sensations are transient and usually of only a few minutes' duration. However, in some cases, the illusions persisted for up to a day (Leonov and Lebedev, 1973).

A perceptual problem described as "unoriented vision" is associated with an empty visual field, in which human accommodation responds by focusing not at optical infinity, but at a relatively short distance of 1-2 m (Whiteside, 1965). In this situation, the individual becomes, in effect, near-sighted, and, partly on this basis, his ability to estimate distances and sizes of objects may be impaired. Such anomalous myopias have been studied as subjects of interest to psychophysicologists (Liebowitz and Owens, 1975) and in relation to practical problems of vision in aviation (Roscoe, 1982). In addition, empty field myopia has significant implications for visual performance in space (Liebowitz et al., 1975).

Soviet scientists measured the optical resolving power of cosmonauts' eyes as well as the number of eye movements per unit time in some of the Voskhod missions. They concluded that, under weightless conditions, the functional capabilities of the eye are subject to definite changes in terms of oculomotor function and visual work capacity (Leonov and Lebedev, 1973). However, the changes were considered to be slight and insignificant in terms of required visual function inflight (Beregovoy, 1979). More recently, Soviet scientists reported decreases in visual contrast sensitivity during the first few days in orbit, and there are indications of a sustained interest in evaluating inflight visual function of the cosmonauts (Schreiber, 1984). No documented reports of inflight impairment of visual function of the U.S. astronauts have come to the attention of the ad hoc Working Group; however, some members of Shuttle crews have complained of "presbyopia" and "misplaced horizon" during flight (Genco and Task, 1984). NASA has conducted testing of visual performance in some of the Shuttle missions by means of a newly developed Portable Vision Function Tester (Genco and Task, 1984). Reports of test results are expected in 1985. Some space flyers have reported seeing objects such as automobiles and ships, that, at the distances involved, were beyond the optical resolving power of the eye (Yuganov and Kopanov, 1975). No satisfactory explanation of such claims has been advanced; however, inference appears to be involved.

Simonov (1975) reviewed the subject of psychophysiological stress of space flight and concluded that "Space flight is accompanied by clear signs of emotional stress." Evidence for

this conclusion has been documented (Gagarin and Lebedev, 1971; Lindsley, 1972). According to Simonov (1975), psychophysiological stress is evoked by informational, not physical, factors: "Signals that are insignificant in their physical characteristics carry information concerning events which are significant for man and only indirectly, through a change in the state of the brain, exert powerful effects on various functions of the organism." Psychophysiological stress is marked by objective signs and symptoms such as shifts in electrical activity of the brain and changes in autonomic and motor functions (Simonov, 1975). Responses to psychophysiological stress are not always negative; that is, some authorities believe that it is necessary to maintain a level of "internal stress" as a means of preserving working capacity, working "tone", and constant readiness (Sevast'yanov, 1979; Simonov et al., 1980).

Simonov (1975) emphasized the importance of developing practical, reliable methods for monitoring inflight crew performance and to diagnose shifts in emotional state so as to institute interventions. Cosmonauts have described instances of interpersonal hostility between members of flight crews; apparently these were related to excessive fatigue and were quickly and amicably resolved (Sevast'yanov, 1979). Instances of hostility in communications between spacecrews and ground controllers have occurred in both the U.S. and Soviet space programs.

In summary, few, if any instances of overt maladaptive emotional responses to stresses of space flight have been documented, and critical psychophysiological functions such as memory, concentration, vigilance, information processing, and decision-making have apparently been unimpaired except for transient decrements in performance during episodes of space sickness (Berry, 1974; Johnston and Dietlein, 1977; Johnston et al., 1975; Vorob'yev et al., 1984). Indeed, striking examples of psychophysiological stability under emergency conditions have been reported; for example, the successful recovery of the Apollo 13 mission following rupture of a main oxygen tank (Johnston et al., 1975).

2. Inflight Psychological Support

Soviet practice in providing psychological supportive measures during missions of 90 d or more suggests a strong conviction of their efficacy. Myasnikov (1983) noted that such measures helped significantly to maintain a high emotional and work "tonus". He wrote:

During the period of the five main expeditions (Salyut-6 missions lasting from 75-185 d, Ed.) an onboard video and record library was organized for the cosmonauts' leisure hours, which included more than 110 spectator and music programs taken from among the best of the Soviet

and foreign screen and stage. A total of 132 meetings were organized for the crews involving 121 representatives of different areas of public life: political reviewers, sports commentators, specialists, scientists, dramatic, film and variety artists who, being the logical source of information for the crews, often of a personal nature, also had a positive psychotherapeutic effect ..."talks with families eliminated nervous stress and invigorated us for more than a day. After the 'meeting' with our families, we were ready to work without demanding rest around the clock"... The efficacy of psychological support, along with other preventive measures, was confirmed both by the statements of the participants of long-term space flights and the results of medical monitoring of the cosmonauts' mental status and work capacity.

Less elaborate measures have been used in the U.S. programs which, except for the Skylab missions, were of relatively short duration when compared with the Salyut-6 and 7 missions. Radio and video communications with families and news networks have helped to maintain morale and to alleviate concerns about families and friends.

3. Anecdotal Information

Despite published reports that mission accomplishment has been unimpaired by behavioral and performance problems, anecdotal information from both Soviet and American experience suggests that instances of altered behavior and performance have occurred. The Working Group recognizes that anecdotal material is both limited and sketchy at best. Indeed, there is no way to document its veracity. Nevertheless, some of these reports provide additional insight into possible problems of behavior and performance in space flight that may be amenable to resolution by research that identifies preventive approaches.

Bluth (1981; 1984) has reviewed mission reports and interviewed a relatively large number of both American and Soviet space flight and ground personnel. According to Bluth (1984):

Both the Americans and Soviets have lost data, ruined experiments, lost equipment, and manifested a long list of symptoms... It includes: fatigue, sleep disorders, irritability, depression, anxiety, mood fluctuation, hostility, social withdrawal, vacillating motivation, boredom, tension, and lowered efficiency.

Bluth (1981) reported that cosmonauts were reluctant to discuss hostility among crew members and between flight- and ground-crews. Errors in distance judgement that compromised docking procedures and disturbance of time sense have occurred (Beregovoy, 1979) as have mistakes in preparation for landing (Leonov, 1979). Helmreich (1984) has noted the similarity of conflicts and instances of lack of cooperation between flight- and groundcrews in both American and Soviet space flights to similar incidents experienced in the Sealab and Tektite experiments. Even though preflight simulations suggest time-lines for procedures during flight and approach and landing are feasible, "time compression" appears to be a recognized phenomenon.

While NASA has instituted operational measures to address these types of problems, their existence suggests that additional careful analysis and definition, together with investigational approaches would enhance operational safety and preserve optimal crew performance.

Unpublished information from the Soviet space program indicates that, during some of the long-term missions, cosmonauts have experienced periods of mental depression for which various intervention techniques were required including private radio talks with their flight surgeons and trusted cosmonaut friends on the ground. Other methods of inflight psychological support of the cosmonauts are noted on page 9.

B. EXPERIENCE FROM ANALOGOUS ACTIVITIES

Marked limitation in the actual numbers of people who have participated in space flights and, more significantly, their relative inaccessibility for expert observation and tests, make it necessary to look elsewhere for information on psychologic aspects of human activities in unusual environments under conditions of confinement and isolation. Environments such as large, multi-crew aircraft, long-range submarines, undersea habitats, and isolated scientific and operational stations with small-to-medium-sized crews have certain characteristics in common with the contemplated space station. They feature physically isolated groups of operational and scientific personnel doing complex and routine tasks over periods of weeks or months. They experience confinement, minimal privacy, and varying degrees of physical discomfort and potential danger. Such enterprises have lent themselves to expert behavioral science observations as well as to limited experiments and tests (Vinograd, 1974).

The occurrence of aberrant psychological, psychosocial, and psychophysiologic responses has been reported during medium and long submarine missions (Earls, 1969; Serxner, 1968; Tansey et al., 1979; Weybrew, 1957); while living and working in undersea habitats (Deutsch, 1971; Helmreich, 1971a, 1973; Radloff and Helmreich,

1968); and while operating polar stations (Gunderson, 1968, 1973; Strange and Klein, 1973). Adverse effects have ranged from boredom and listlessness through heightened anxiety with psychosomatic symptoms, sleep disturbances, fatigue, and impaired cognition to irritability, hostility, depression, and deterioration of personality. Table 2 lists examples of observed responses. Despite the stressful nature of some of the listed environments and the associated performance requirements, human ability to adapt and perform effectively in such circumstances has repeatedly been demonstrated.

Psychological and psychosocial studies of crews and test subjects involved in such space analogues have identified positive and negative behavioral responses, stressful environmental factors, and personal qualities favoring successful participation. They have defined individual and group factors that promote group cohesion, improve morale, and support improved performance (Angiboust, 1967; Chambers, 1964; Chambers and Fried, 1963; Kubis, 1972; NASA, 1966; Smith, 1969; Trego and Sells, 1970). Data, procedures, and scientific principles derived from such studies are applicable to the space station as well as to the Shuttle Program, in terms of crew selection and training, improved habitability and psychological support. Moreover, such information could facilitate the development within NASA of urgently needed capabilities for participation of behavioral scientists in NASA's training programs, space mission simulations, Shuttle flights, detailed task analyses of space- and groundcrews and design studies of the space station itself.

C. PAST RECOMMENDATIONS OF SCIENTIFIC ADVISORY GROUPS

Comparison of the recommendations of past scientific advisory groups with the current research program (RTOP No. 199-22-62, Psychology; see page 33), suggests that widely divergent views on the value of research in this field have long existed in NASA. A major study initiated in 1967 by the Space Science Board of the National Academy of Sciences on biomedical and human factors aspects of manned space flight identified important gaps in knowledge and recommended substantial research in pertinent areas of the behavioral sciences (Lindsley, 1972). An ad hoc panel responded to a NASA request for assessment of its research program on behavior and performance, noting lack of: (1) an overall strategy for the program; (2) consideration of long-duration space missions with autonomous crews; and (3) consideration of the psychosocial aspects of manned space missions (Neff, 1977).

NASA's program in human behavior and performance was appraised by the Life Sciences Advisory Committee of the NASA Advisory Council (Whedon, 1978). Overall, the Committee regarded the efforts and priorities in the contemporary activity as adequate to support NASA's planned programs. They recognized, however, that new social and behavioral questions regarding small

Table 2. Effects of Isolation and/or Confinement on Human Behavior

Setting	Behavioral Observations	Comment	Source
<u>Underwater Habitat</u>			
Ben Franklin, 6 subjects, 30-d in cylindrical submersible 10' diam., 48' long	High motivation, morale; no psychomotor decrement; some tension, transient depression; discontent directed toward topside personnel	No professional or maintenance difficulties; chief complaint: lack of privacy	Del Vecchio et al., 1970; Grumman Aerospace Corp., 1970
Sealab II, three 10-man teams, 15-d each in submersible 12.5' diam., 57.5' long, at 205' depth, LaJolla, CA	Social interaction strongly related to adaptation; older, later-born divers from small towns adjusted best; high morale, motivation and diving experience favored good performance; some decrement in psychomotor performance as complexity of tests increased	No overt maladaptive responses	Helmreich, 1967; Pauli and Clapper, 1967; Radloff and Helmreich, 1968
Tektite II, four 5-person teams 14-d each; six 5-person teams, 20-d in submerged habitat; 2 cylinders 12.5' diam., 18' high, tunnel-connected, at 49' depth, Virgin Is.	Gregariousness correlated positively with performance; very little anxiety or depression; few interpersonal conflicts; positive moods prevailed but weakened as missions progressed; role-sharing increased productivity and cohesiveness	Privacy was an important factor; methods used for behavioral assessment were verified	Helmreich, 1971b, 1972; Miller et al., 1971
<u>Submarines</u>			
Polaris nuclear submarine, 2 crews of 140 men, two 60-d runs	Sleep disturbances common; headaches; decline in mood and a depressive trend peaked at 4-5 wk with introspection and social withdrawal; some noted poor concentration, reduced alertness; sex a favorite topic; pecking orders were established; irritability; vulgar language; feuds between small groups; moods improved at 6-7 wk; "hypomanic" at end of 8th wk, sense of well-being	Prominent adverse factors: lack of objective reward; no ability to communicate with outside persons; crowding; unchanging environment; family concerns; onboard nuclear weapons	Earls, 1969; Serxner, 1968; Weybrew, 1963

Table 2. (continued)

Setting	Behavioral Observations	Comment	Source
<u>Isolated Stations</u>			
Antarctic station, 85 men, about 1-y	Tension, headaches, sleep disturbances, reduced intellectual energy, impaired concentration; increased appetite and weight gain	Principal psychologic stresses were group adjustment problems, unvarying environment, absence of some customary sources of emotional satisfaction	Mullin, 1960
Antarctic station: studies of scientists and naval personnel in prolonged isolation	Sleep disturbances, depression, tension, headaches, irritability, reduced work satisfaction, social relationships, and group accomplishments	Size of groups was unrelated to somatic and emotional symptoms	Gunderson and Nelson, 1963
Review of studies of Arctic remote stations (2-12 mo) and Antarctic stations (4-12 mo)	Decreased morale and performance, anxiety, boredom, day-dreaming, irritability, depression, and hostility	Principal stresses were lack of privacy and social stimuli; informal group structures evolved including choosing "emot- tional leaders"; good leadership supported emotional and social needs of crews, improved cohesion and performance	Kubis, 1972
Antarctic station, 27 men 1-y	Tension, headaches, pains in hearts, muscles, joints; "asthenoneurotic syn- drome" after onset of polar night (headaches, unstable mood, decreased libido, restless sleep, itching, derm- atographism, constipation); emotional uplift with return of day, but neuro- psychologic status did not improve; hostility and conflict between individ- uals and between informal subgroups that formed after 5-6 mo.	Results of hematologic, hormonal, and immuno- logic tests described as consistent with the behavioral responses	Kurbanov et al., 1977

Table 2. (continued)

Setting	Behavioral Observations	Comment	Source
<u>Space Flight Simulation</u>			
Three 30-d runs, two with 4 men, one with 5; different cabin atmospheres and life support systems (LSS); 8-h sleep in one, 7-h in one, and a 4-on 8-off schedule in third	Group adjustment good in one test, marginal in two; motivation high in one, indifferent in one; poor in third; cognitive function, performance, and psychologic stability good in all runs; irritability and hostility in one test; attitude toward outside monitors positive in one test, negative in two	Curtailed social stimulation and boredom were negative factors; environments not particularly stressful; careful selection and pre-test training optimized motivation, cohesiveness, and group performance	Boeing Co., 1964; Dunlap, 1964; General Electric Co., 1964.
A 60-d mission, 4 college volunteers, closed LSS; sleep 8-h for each of 2 shifts; tasks: domestic chores, operate and maintain LSS; perceptual motor and behavioral tests	Minor interpersonal conflicts; friction between subjects and outside monitors; crew function good throughout; psychologic status remained good; perceptual motor skills unchanged or improved; crew functioned smoothly	Careful selection and pre-mission training including group dynamics. Noise, insomnia, food were irritants	McDonnell Douglas Astronautics Co., 1968.
A 90-d mission, 4 college volunteers, closed ecological system, 100% oxygen; sleep, 8-h for each of 2 shifts; tasks same as in 60-d mission (above)	Slight improvement in performance and less time per task as mission progressed; high cognitive performance; some sleep disturbance; good morale except 10-d at 6-7 wk; transient hostilities; tension noteworthy in two, anxiety in one; increased affect needs in one; no friction with monitors; little group cohesiveness developed	Careful selection and pre-mission training were employed	Jackson et al., 1972; Pearson and Grana, 1971; Seeman and MacFarland, 1972

group interactions might arise as types and durations of space missions change in the future and as the composition of space teams diversifies. They recommended that research on behavior and performance continue to be supported because of the long lead times required "to achieve practically usable information for application to operational space flight requirements."

Another major study of NASA's needs in the space life sciences conducted by the Committee on Space Biology and Medicine of the Space Science Board excluded consideration of behavioral and social problems except for reference to the existence of psychosocial stressors and spatial illusions during space missions, a suggestion that biofeedback techniques be further explored in relation to space sickness, and recommendations for additional studies of protective adaptation to motion sickness (Bricker, 1979).

In 1980, a NASA advisory panel (Kubis, 1980) recommended considerable expansion of NASA's research in behavior and performance to include: (1) total system studies, including ground-based and space flight teams; (2) behavioral and social interactions of spacecrews and groundcrews composed of astronauts, nonastronaut scientists and others, of both sexes and different races; (3) designation and management of authority in the system; (4) performance including measurements during Shuttle simulations at JSC; (5) long-term maintenance of critical performance skills; (6) causes and diagnosis of mental overload, including development of onboard monitoring capability; (7) development of means to identify "systems overload" and to monitor system trends; (8) optimal division of function between automated and crew-operated parts of the space system; and (9) behavioral medicine as a preventive and supportive approach to optimal performance. In addition, the panel recommended that NASA maintain competence in the science of biorhythms as they relate to fatigue, alertness, sustained performance, work/rest patterns, and social interaction.

A more recent evaluation of NASA's research needs in human behavior (Brady, 1983) emphasized the desirability of an expanded behavioral science data base to support future space missions. A series of recommendations was made for further research in this area. Areas included: (1) selection, training, and organization functions; (2) physiological adaptation and stability; (3) operational performance requirements and general living conditions; (4) conceptual and methodological approaches to long-term research requirements; and (5) general implementation considerations.

NASA has requested and received over the years, a number of suggestions and reports on aspects of human behavior and performance in short- and long-term space missions. As with most previous expert groups, the LSRO ad hoc Working Group on Behavior and Performance is convinced of the practical potential of an

expanded research program that will provide data and procedures for optimizing individual and group performance of both space- and groundcrews in future missions of both the Shuttle and the space station (see Sections IV and V).

IV. OBSERVATIONS OF THE LSRO ad hoc WORKING GROUP ON BEHAVIOR AND PERFORMANCE

The Working Group represents broad expert investigative experience in such pertinent areas as experimental, cognitive, engineering, and social psychology, psychiatry, and aerospace medicine (see list of participants in Section VII). In addition, four members have participated in NASA activities either directly, contractually, or as scientific advisors. Information sources available to the ad hoc Group included detailed written and oral descriptions of NASA's current research in psychology, selections from the literature, briefings on psychological and social problems of space flight, and plans for the space station from the point of view of the life sciences.

A. DETERMINANTS OF HUMAN BEHAVIOR AND PSYCHOLOGICAL WELL-BEING

The principal factors that influence the behavioral responses of spacecrew and associated operational personnel are listed in Table 1. Certain of these were considered in detail by the ad hoc Group; however, an absence of comment on some of the items in the table should not suggest they are considered unimportant as factors that may affect behavior and performance.

1. Current State of Knowledge

a. Perception

The small inflight alterations of visual performance parameters reported by Soviet investigators (see page 8) tend toward preflight values as missions proceed, and Soviet space medical scientists have concluded that inflight visual function is as reliable as on Earth (Nicogossian and Parker, 1982). Moreover, the essentially negative results of tests to detect inflight and postflight changes in visual performance during the Gemini program (Nicogossian and Parker, 1982) and the apparent lack of aberrations of visual performance in the Apollo and Skylab missions have not suggested a need for much further scientific investigation of visual performance in space flight. However, as noted on page 8, some transitory changes in visual performance have been reported, and NASA is conducting more sophisticated tests of inflight visual function than have been feasible in the past. Moreover, improved means of aiding optical accommodation for distant objects in unstructured visual fields are needed; for example, a device that projects a pattern at infinity (Whiteside, 1965) and methods of accommodation control (Roscoe, 1982).

Similarly, future plans should include precision inflight measurement of hearing, made at selected times during a mission including the early hours and days. In addition, inflight tests should be devised to detect possible changes in olfaction and gustation. NASA's current program for inflight assessment of vestibular function is probably sufficient; however, instances of disorientation during orbital insertion and reentry appear to be inadequately defined, especially as regards operational significance. Such disorientation should be the subject of expert inflight observation and, if feasible, follow-up ground-based investigation.

b. Cognition

One perceptual-cognitive phenomenon that should be investigated scientifically is so-called "time compression" (see page 11). It is understood that NASA has alleviated this problem of apparent operator overload during Shuttle landing approach by operational means; however, time compression is not well enough defined to be set aside as insignificant. It probably contains elements of excessive mental workload, information overload, and cognitive processing involving inferences, judgment, and decision-making, for which the data bases are insufficient. For instance, Sheridan et al. (1983) noted: "For human supervision to be really effective, a detailed understanding of how the human controller grasps a complex system at any moment in time and updates it over time is necessary." Elucidating the mental processes involved in the overloaded operator will require substantial additional research in such areas as cognitive systems (Landman and Hunt, 1982; Navon and Gopher, 1979; Posner, 1978, 1980), mental workload, inferencing, reasoning, and decision-making, and the interaction of stress, emotions, attention and cognitive processes (Bower, 1981; Posner and Rothbart, 1980).

LSRO is aware that NASA employs a systematic procedure for investigating operational incidents. Careful analysis of such incidents may offer a valuable approach to improving flight safety, operator performance, and development of preventive techniques. For example, in the Air Force, flight safety, crew performance, and human engineering design of workspaces, displays, and controls have benefited from critical incident reporting and analysis (Fitts and Jones, 1947a,b; Sinaiko, 1961).

c. Perceptual-motor Function

Experience with manned space flight and extravehicular activity (EVA) suggests that, for the tasks performed to date, no serious impairments of perceptual-motor functions have occurred. This includes extensive Soviet experience, American EVA experience on the Moon (288 man-hours), 10 EVAs (82 man-hours) to

repair the Skylab Orbiter Workshop, and a considerable accumulation of EVA experience in the Shuttle Program. Rapid adaptation of perceptual-motor functions in weightlessness has evidently occurred in all space flights. On the other hand, impaired motor function has been common after long missions, and vigorous inflight exercises have failed to prevent it. Atrophy of skeletal muscle accompanied by a decrease in muscle strength has been documented in the Skylab Program and other long-term flights (Gazenko et al., 1981; Herbison and Talbot, 1984; Thornton and Rummel, 1977). Whether degradation in neuromuscular control of fine movements of the hands and fingers may occur in these circumstances is not known, but should be investigated despite the generally accepted conclusion that spacecrew performance has been equal to the operational requirements of given missions.

d. Psychological Stability

Psychological stability, a mandatory characteristic of candidates for spacecrews (Kubis and McLaughlin, 1967; Loftus et al., 1975), is generally considered a part of the make-up of a normal individual. In space flight, as in other more or less stressful endeavors, maintaining psychological stability depends upon such factors as intelligence, physical and mental adaptability, physiologic homeostasis, motivation, training, experience, and maturity. The physical environment, workload, mission duration, and emotional responses to interpersonal annoyances, hazardous incidents, environmental monotony, physical discomfort, and other elements all can influence psychological stability.

Personality traits considered desirable in members of spacecrews have been identified and are taken into account in the selection process (Chambers and Fried, 1963; Epstein, 1980; Leonov and Lebedev, 1973; McGuire, 1984a; Ruff and Levy, 1959; Trego and Sells, 1970). With regard to the psychological aspects of selection, NASA currently relies on the results of expert psychiatric interviews to identify persons with appropriate psychological characteristics and to eliminate from consideration those with psychopathology.

In the opinion of the ad hoc Working Group, available knowledge is adequate for optimal psychological selection of individuals for space- and groundcrews. On the other hand, despite some progress in identifying favorable personality characteristics and procedural influences (Brady and Emurian, 1979; Emurian and Brady, 1984; Helmreich, 1983; Helmreich et al., 1980a,b), currently available information is insufficient on how to select persons who will be the most compatible in dyads, triads, or larger groups. For the space station, as an example, crew selection and high technical proficiency will not guarantee a cohesive, smoothly functioning group. In the past, a valuable means of demonstrating the probability of crew compatibility involved years or months of

intimate, premission association in training and recreation. This may be a feasible part of the crew familiarization process for the space station. In addition to the customary intensive training programs for each space system and careful organization of the crew in terms of leadership, functional structure, and allocation of responsibilities, plans should include social sensitivity training and sufficient cross-training in specialized technical skills to permit some rotation of members in and out of the more interesting mission activities. Such role sharing has been shown to improve group cohesiveness and productivity (Helmreich, 1972; Helmreich and Radloff, 1973).

Fatigue has proved to be a particularly important negative influence on psychological stability, human reliability, and productivity. Means for its prevention have been identified from cumulative space flight experience, adequate sleep being the most significant element (Loftus et al., 1975). Space station design and mission planning will, no doubt, emphasize provisions for adequate sleep.

e. Motivation

The powerful influence of motivation as a prime mover of human accomplishment is widely recognized. It will be a keystone of productivity in the space station as well as in future Shuttle missions. Expert opinion suggests that developing and maintaining good motivation may prove difficult for long, relatively routine missions that may lack the glamour and pioneering interest and stimulation of earlier manned space programs. If this supposition is correct, the need for identifying and implementing methods of assuring proper motivation appears essential. Involved are such issues as space system organization, command and control, space station autonomy, role sharing, psychological support, career development, growth potential, and incentives. Assistance in these areas is available from a number of disciplines in the behavioral and social sciences including the following branches of the broad field of psychology: clinical, counseling, community, engineering, environmental, experimental, industrial/organizational, and social.

f. Performance

Two aspects of the subject of crew performance were emphasized by the ad hoc Working Group: lack of expert assessment by behavioral scientists during preflight training, simulations, and inflight; and the inadequate state of knowledge of group performance under conditions of emotional stress such as in emergencies. Despite the impressive records of achievement in the American and Soviet manned space programs, questions have arisen on whether crew performance has generally been optimal and,

if not, what were the causes? No data from actual performance assessments of spacecrew members were available to the Working Group.

In view of the current planning emphasis on productivity of the future space station crews (Cramer, 1984), and in the Shuttle Program, a need for performance assessment appears clear. Here, the objective would be to improve operator performance, not to test personnel on a pass-or-fail basis. The introduction of performance assessment would offer substantial gains in the quest for optimal productivity. Some suggested methods are treated in Section IV B (see pages 27-29).

Reliable predictive data based on actual space flights are not available on the likelihood of significant performance degradation from possible adverse behavioral effects of long-term occupancy of a multi-crew space station. Moreover, insufficient information is available accurately to predict whether crews will take effective, coordinated action in inflight emergencies or situations requiring improvisation. Some evidence suggests that failure of coordinated action by crews in large transport aircraft has been responsible for accidents and serious inflight incidents (Cooper, 1982). Whether well-trained crews may be expected to react as decisively and effectively to an inflight emergency as did the crew of Apollo 13 (Johnston et al., 1975) is problematical. To improve crew coordination in airliners, some airlines have recently added formal crew coordination indoctrination and full mission simulation to their training programs, but their potential effectiveness has yet to be demonstrated. In NASA, validation of such techniques would require access of behavioral scientists to observe spacecrew members during their training and inflight.

A major potential contributor to successful spacecrew composition and productivity is psychological, as distinguished from psychiatric, appraisal. Refinements in the potential of psychological selection may be expected because of recent advances in understanding relationships between individual and group performance, certain personality traits, and real-life situations that influence behavior. For instance, two major clusters of personality traits have been shown to correlate strongly with individual and group interactions and performance. One cluster involves individual or group achievement, the other, concern for others, empathy, and emotional reactivity (Helmreich, 1984; Spence and Helmreich, 1978). Superior performance has been shown to be associated with the two groups of traits. Generally, individuals possessing both clusters of traits appear advantaged in, "...self esteem, life satisfaction, marital adjustment, general achievement, and ability to perform in group settings" (Helmreich, 1984).

Moreover, they tend not to become neurotic or to require therapeutic assistance. Achievement motivation has revealed some weakness as a predictor of successful performance in real-world situations. Three of its measurable components, mastery, work, and competitiveness, have been shown to relate differentially and frequently interactively with a variety of criterion measures (Helmreich and Spence, 1978; Helmreich, et al., 1980a; Spence and Helmreich, 1983). For example, in multi-person air transport crews, work was unrelated, mastery was positively related, and competitiveness negatively related to crew performance (Spence and Helmreich, 1978).

g. Small Group Dynamics

An opinion that has often been expressed by authorities in astronautics and the space life sciences holds that the feasibility of future long-duration space missions will depend upon solution of the associated psychosocial problems of heterogeneous crews living and working in isolation and confinement (Bell, 1981; Berry, 1973; Brady, 1983; Novikov, 1979; Vorob'yev et al., 1984). One Skylab astronaut was convinced of this when he noted that the sociological problems will prove more difficult to solve than the technical ones (Bell, 1981). One veteran Cosmonaut stated, with regard to interpersonal relations on a 6-mo Salyut mission:

We must now adjust to living together. Away from the rest of the world...We have to solve ours (problems) together, taking into account the feelings of the other. True, we had prepared for this long and hard together, rehearsing every anticipated problem, but this was done in an environment of other people. Here we are totally alone. Each uttered word assumes added importance. One must bear in mind constantly the other's good and bad sides, anticipate his thinking, the ramifications of a wrong utterance blown out of proportion. (Quoted in Bluth, 1981.)

According to Novikov (1979) development of fundamental data on psychological compatibility and criteria for the selection of groups such as those contemplated for the space station are outstanding examples of unsolved problems of group psychology. He noted the difficulty of analyzing motivation and the contemporary absence of scientific methodology for this (however, for examples of progress in this area, see page 23). He emphasized the importance of studying the social-psychological mobility of personality, that is, the ability to adapt to group isolation, the role of self-regulation, and the need to develop methods of group psychological training and skills of joint action. He stressed as well

the essentiality of clear assignments of responsibilities and duties in order to avoid conflict tension (Novikov, 1979). The importance of avoiding role ambiguity and conflict was amply demonstrated in the Spacelab Mission Development Tests III (SMD III) simulation of the Spacelab mission (Helmreich et al., 1979). For instance, a potential for conflict was identified between spacecrew members and ground controllers and between ground-based scientists in charge of inflight experiments and their spaceborne scientific collaborators (Bluth and McNeal, 1981; Helmreich et al., 1979).

Interviews with experienced cosmonauts and astronauts and reviews of their writings confirmed the occurrence of psychological and psychosocial problems in highly selected, well-trained spacecrews with rather homogeneous backgrounds. When cultural backgrounds of crew members and members of other groups operating in isolation and confinement were quite different, the behavioral reactions were further complicated (Bluth, 1984).

While the data and principles pertaining to group behavior derived from space flight experience, space flight simulations, and analogous activities are extremely valuable, they are not always well enough developed in certain domains to provide the degree of confidence needed for specific planning and design of space systems; nor has the available information been put to optimal use in such critical areas as selection and training.

h. Environmental Considerations

The biomedical effects of exposures of up to 6 mo of continuous space flight in the Salyut-6-Soyuz program have been reported (Gazenko et al., 1981; Vorob'yev et al., 1984). In addition, Gazenko (1983) summed up the 211-d mission of Salyut-7, flown in 1982, with the words, "In comparison with flights of shorter duration, space flights lasting up to 7 months do not lead to any qualitatively new biological changes in the human organism." No medical or psychological data from the recent 8-mo Russian mission have come to the attention of the Working Group, but, considering the Soviet capabilities for inflight medical and psychological assessment of the crew, one may assume that this mission was also a success from the point of view of the involved life scientists and flight surgeons.

Except for space sickness and transient illusions of spatial disorientation, all of which disappeared after the first few days in orbit, no inflight psychophysiological impairment was reported by the Soviet scientists. Behavioral disturbances in the long Soviet missions have apparently been infrequent and nondisruptive. Temporary postflight disturbances of vestibular function, posture, gastrointestinal stability, and locomotion have commonly occurred in cosmonauts and astronauts (Homick, 1979; Yakovleva et al., 1981).

As a result of the successes of the space missions and the apparent lack of irreversible biological effects in the crews, estimates by space medical authorities are generally optimistic about extending the missions to greater and greater durations (Berry, 1973; Gazenko et al., 1981; Vorob'yev et al., 1984). The achievements in the Soviet long-term flights have been credited in part to the contributions of the behavioral sciences in such areas as psychological criteria for crew selection, psychological methods of training and preparing crews for space missions, inflight psychological monitoring and support, and the use of behavioral science principles and techniques to maintain motivation and productivity.

In general, the biobehavioral effects of human exposure to near-Earth and Earth-Moon space for missions of varying length have been within acceptable limits and, except for the unpredictability of solar particle events, the nominal 90-d space station mission should present no exceptional problems from the point of view of the space environment. Within the space station however, environmental factors will have a marked influence on individual and group behavior. Provision of state-of-the-art habitability in all its manifold ramifications, will be a major determinant of success in the space station as will expert selection, organization, and training of the crew and allocation of functions. The Soviet practice of permitting spacecrew members some latitude with respect to designing their flight suits, selecting some of their favorite items for onboard recreation, and requesting favorite foods via the resupply flights reportedly has helped to maintain morale and productivity (Bluth, 1981). While some useful information is available about human needs for contact, privacy, and personal space and about crowding (Altman, 1975; Baum and Valins, 1977; Worchel, 1977), the data base is limited in terms of privacy needs and methods of meeting them in confined environments. Moreover, data are lacking on some of the more subtle psychological aspects of habitability.

In the Salyut-6 station, cosmonauts have managed some degree of psychological privacy by writing their impressions and feelings in their diaries (Bluth, 1981). Other relatively simple means for improving onboard privacy, or its perception, might include back-to-back work stations and limitation of video monitoring to a single work station rather than all occupied parts of the space station (Bluth and McNeal, 1981). However, the capability for video and audio monitoring of all habitable spaces in the space station may be required for non-biomedical reasons, and it would be highly desirable as a means of expert observation of crew behavior and performance, particularly in the "shake down" phases of space station operation.

The need for privacy of space-ground radio communication for crew members with their families, flight surgeons, fellow astronauts in mission control, and others has been repeatedly

emphasized by American and Soviet space medical authorities as essential for maintaining morale, solving personal problems, and reducing emotional stress. It is understood that the privacy of the personal radio link has been so undependable that spacecrew members do not trust it. Extraordinary effort should be expended to provide secure means of private communication between spacecraft and ground.

B. METHODOLOGY AND MODELS

NASA's documented objectives in Psychology (see Section IV C) clearly point toward a need for employing the most appropriate available investigative methodology and developing improved methods, equipment, and models for use in studying behavior and performance. Discussion of these topics suggested that certain applicable methods and equipment are available but not being used in NASA research, as well as lack of suitable methodology for exploring some problems of interest to NASA. With respect to models of human behavior, one of NASA's stated goals is to develop a model relating behavior and performance to the environmental influences and performance requirements of a space system. The opinions of the Working Group on these subjects are presented in the following paragraphs.

1. Methodology

As was already mentioned, the most serious lack of data pertains to the performance of astronauts and other crew members during training, simulations, and actual space flight. To acquire the means of improving inflight performance of operators as individuals or members of crews, data from the "real world" of training and space flight derived from expert observations and measurements of actual crew members are essential.

A technique that has proved valuable in assessing workload in Air Force aircrew members is the embedded secondary task method. The basic concept of this technique is to use as the measuring instrument a function which the crew member must perform as part of the mission. For example, radio communications, which normally must be performed in any case, can be quantified with respect to workload or performance parameters. Messages could then be introduced to the operator at specific times in the mission which require known responses. In this way, the well-recognized advantages of secondary task methodology in assessing workload are obtained without the intrusiveness or artificiality typically experienced with that method. The Air Force has quantified communication tasks in the A-10 aircraft, and has shown good reliability for the technique (Shingledecker and Crabtree, 1982). Using this model, one could select a number of mission sub-elements, quantify them with respect to workload or performance

expectation, and use them as embedded secondary tasks. Other approaches to workload assessment are described in Kerr (1973) and Wickens (1984).

The extremely limited information available on details of spacecrew performance inflight was regarded as a pivotal gap in essential knowledge for identifying clues for improving design, operational procedures, training, and formulation of research plans. The Working Group advocated crew performance assessment in all space flights as well as in ground training and simulations including participation by expert behavioral scientists--even a behaviorally trained professional "just to be there and look" would be a valuable step forward. As a beginning, NASA needs a carefully recorded but protected cataloging of psychological events in training, simulations, and inflight.

Techniques for identifying reactions to stress in Navy divers have been developed and refined for research and operational use. These include observation by video or sequential photography, voice analysis, measurement of intention tremor, and pencil and paper devices for examining types and characteristics of personality and attitudes in divers. Use of the pencil and paper devices has helped to distinguish, for example, successful high-risk personnel who, no matter what the stress situation, appear to have elements in common. Examples of such elements include a low, generalized anxiety level, a strong sense of self-confidence, and of being in control, and a strong potential for social support, for example via help, advice, and cooperation, as well as the capacity to receive social support in a similar fashion. The potential for social support is important in view of certain stereotypes pertaining to "heroes". The loner or the "macho" performer is not as successful in overall high-risk performance, especially in view of increasing requirements for team performance.

It is feasible to embed the intention tremor device so that its use is unobtrusive. In addition, changes in rate and pattern of respiration are useful and virtually universal indicators of impending stress in all situations and should be considered as another practical means of monitoring psychophysiological status and assessing reactions to the environmental and situational influences of space flight.

Although NASA has supported the development of several performance tests, and is currently supporting development of a series of tests at Johnson Space Center, the ad hoc Working Group feels that there is a need to utilize a more coherent, comprehensive, and theoretically defensible performance assessment battery in the program. One such battery, which is nearing completion of its developmental phase for the military services in connection with defense against chemical warfare agents is regarded by members of the ad hoc Working Group as superior to any other available

system for its intended uses. This type of system is discussed in Thorne et al. (1983). It would be an excellent means of assessing some of the behavioral effects of space flight on a before-and-after basis, and it appears to have potential for modification for onboard use. A method that has facilitated the timely introduction of psychological and human factors expertise into the early design phases of Air Force weapon systems is known as the Cockpit Automation Technology Program (CAT), whose purpose is to assure that cockpit design is optimal for human performance. A system of this sort may offer some advantages in designing work stations or other crew spaces of the space station.

An excellent opportunity apparently exists for acquiring abundant data unobtrusively on spacecrew behavior and performance via the video and audio systems on the Shuttle Orbiter. Similar opportunities should obtain for the space station. For example, with approval by NASA, one could video- and audio-tape the spacecrew during representative segments of a mission, not merely brief transient recordings. Very good, sophisticated techniques are available for analyzing unobtrusive data in such areas as performance parameters, social interactions, and nonverbal behavior.

From such information could come a series of descriptive analyses of doing ordinary things such as brushing teeth, washing, and other basic tasks of living onboard as well as the more complex tasks of operating and maintaining the space vehicle, communicating, and functioning in the scientific and technical spheres. Moreover, experience with unobtrusive behavioral observations of this sort should lead to improved means of monitoring spacecrews for psychophysiological stability and detection of maladaptive trends or events requiring intervention.

Numerous applied methods of research, test, and analysis are available. For instance, one aerospace company that has an outstanding human factors capability uses 45 techniques and methods. However, fundamental information regarding such criteria as reliability, validity, sensitivity, and generalizability of the methods is usually lacking; hence, the practitioner must rely heavily on his past experience and treat each new applied problem very much on an ad hoc basis. Indeed, most human factors practitioners actually use a very restricted number of the available techniques. Task analysis, functions allocation, timelines, sequence diagrams, interviews, questionnaires, rating scales, mock-ups, and computer-based simulation are among those most in favor.

There is clearly a need to develop thorough, descriptive information and criterion-based data that will enable the human factors practitioners to select and properly to employ the most appropriate methods in their attempts to assure that people are employed so as to maximize systems effectiveness (as measured by the criteria established for a particular system).

Another area of great practical interest involving a need for progress in methodology concerns identification and classification of stress-tolerant people and means of preparing individuals and groups for coping with the stresses of space flights. Examples include methods for self-control such as relaxation techniques, control of autonomic responses using biofeedback, and psychological self-defense. Pertinent references include Benson (1984), Henry and Stephens (1977), Mason (1975), McGuire (1984b), Orne (1980), Schultz and Luthe (1959), Selye (1974), and Wolpe (1973). In this general area belong, as well, methods for teaching elements of group dynamics such as social sensitivity, awareness of each other's needs, and how to interact with other members of the space and groundcrews to achieve the mission objectives cooperatively and efficiently.

2. Models

Conceptual Model of Program. It might prove beneficial to organize the factors identified in Table 1, and other potentially important variables, into a preliminary conceptual model of space crew performance. The model could identify the major categories of variables or factors that influence performance along with the principal dimensions of each category as presently known or hypothesized. Appropriate theory and empirical research findings could be used to develop the variables and relationships reflected in the initial version of the model. Such a model could provide: (1) a coherent blueprint of the research arena and principal variables under investigation; (2) a framework or foundation for classifying important variables, reflecting known or hypothesized relationships, developing research propositions, identifying variables for multivariate experimental investigations, and prioritizing research; and (3) a taxonomy for cataloging research findings, incorporating new knowledge, refining theory, and identifying knowledge gaps.

Development of another potentially useful conceptual model, based on the notion of generic human effectiveness, reached preliminary stages in the mid-1970s. It concerned the influence of personal, organizational, and environmental (physical environment) variables on performance (particularly that of scientists and engineers). The original reports are voluminous and not directly applicable to NASA's needs; however, summaries of portions of this work are available (Secrist, 1983a,b). For example, the total spectrum generic model of human effectiveness identifies certain dimensions of the organizational and physical environments that also apply to space crews. The dimensions (Secrist, 1983a) and efforts to develop measures of those with satisfactory psychometric characteristics (Secrist, 1983b) have been described.

Other models that have proved useful in the behavioral sciences may be divided, albeit somewhat arbitrarily, into three classes: physical, manual control, and perceptual-cognitive.

a. Physical. Fairly sophisticated models have been developed for use in workplace design. Table 3, taken from Roe-buck, et al. (1975), shows some of the unique requirements engendered by operations in space. Specific models are available for examining such parameters as reach, physical clearances, effects of selected encumbrances, and vision. Adaptation of some models for computer treatment has greatly facilitated their application. (See, for example, Kroemer, 1972; McDaniel, 1980). We are unaware of studies that examined the significant parameters over extended periods of time.

b. Manual Control. The pioneering efforts of Askenas and McReur (1962) are a classic example of where brilliant insight and well-conducted experiments led to what many consider the most comprehensive program of modeling in the human factors area. Sophisticated treatments were required to deal with control problems involving six degrees of freedom and such factors as the non-linearities of the human controller.

Those engaged in this area of research and applications became almost a fraternal organization, meeting once a year in what came to be known as the "Annual Manual". The 20th Annual Manual was held in 1984 and featured for the first time "annual mental" sessions--a clear recognition of the intimate interrelationships between the motor and cognitive; these sessions addressed such topics as evoked potentials, workload, communications, diagnostics, and supervisory control (Anonymous, 1984). Manual control models, supported by simulator test, are available to solve a wide variety of human-machine problems.

c. Perceptual-cognitive. The extension of the manual control conference into the perceptual-cognitive area is clear recognition of the fact that the human organism, in and of itself, is a complex system. While selected sub-systems such as the physical and the motor have yielded much information to the systematic inquiry of the modelers, only a very preliminary understanding has developed with respect to the cognitive sub-systems. Adequate treatment of the entire human performance system is not foreseeable at this time. Interaction of the human system with complex technological systems will necessarily remain largely ad hoc for the foreseeable future. However, significant information is available with respect to the design of controls and displays, information processing, and effects of selected environmental parameters.

Table 3. Spacecraft Design Areas with Unique Anthropometric Considerations

<u>Design Area</u>	<u>Unique Considerations</u>
Crew couch and body supports	Reentry and launch loads, supine position, space-suit mobility and bulk, landing impact, weightlessness, astronaut population dimensions.
Controls, latches, and hand holds	Space-suit glove bulk, mobility limitations. Space-suit reduction of tactile sensation. Suit lead and abrasion sensitivity. Astronaut population strength.
Personal equipment	Space-suit interface shape, connections, mobility limits, visibility limits.
Hatches and tunnels	Space-suit bulk and limited mobility, zero-G locomotion, vacuum environment, metabolic costs, suit safety.
Portable environmental control systems	Zero-G, need for suit support, suit mobility and vision. Metabolic requirements for suits.
Tool design	Space-suit glove: limited mobility and bulk. Weightlessness. Loss of traction, use of tethers for restraints.
Restraints and tethers	Weightlessness requirements.
Personal maneuvering units	Six degrees of freedom--no friction. Weightlessness, space-suit bulk, contour, and mobility limits. Lighting and vision.
Clothing	Space suit, helmet, gloves, boots. Astronaut population.
Emergency ground egress and rescue	Space-suit bulk, weight, and mobility limits. Supine position, pressurized vessel. Oxygen environment fire hazard. Umbilical tower environment. Astronaut training and agility.

Source: Roebuck et al., 1975, (with permission).

However, adequate models for handling such matters as cognitive workload, decision making, and supervisory control are yet to be developed, although considerable promising work is being conducted. Sheridan et al. (1983) summarize very well the research needs in the area of supervisory control systems: (1) computer-operator communication; (2) discovering cognitive models of operator-controlled processes; (3) computer-based aids to cognition; (4) system reliability and reasons for human error; (5) definition of mental workload and its effects on human error; (6) division of authority between human operator and computer; (7) coordination of supervisory control teams; (8) extracting knowledge from experience with large, complex, interactive systems; and (9) improving communication between designers and operators of supervisory control systems.

C. NASA-SPONSORED RESEARCH AND TECHNOLOGY IN THE BEHAVIORAL SCIENCES

NASA supports intra- and extramural research and development in the psychological aspects of space flight (Research and Technology Objective and Plan [RTOP] No. 199-22-62, Psychology) and in aeronautical and space human factors. In addition, several tasks with implications for human behavior and performance are parts of other NASA RTOPs, such as studies of the space adaptation syndrome, the effects of certain foods and nutrients on behavior, and the behavioral effects of altering normal circadian rhythms. NASA's formal Human Factors Program, while outside the scope of this study, is closely related and would benefit from results of basic research suggested in Section V. To improve awareness and essential interactions, the ad hoc Working group believes that close and sustained coordination should be continued among all NASA activities that are involved in research and development in the behavioral and closely related sciences.

NASA relies primarily on unsolicited research proposals to meet its research program needs in psychology; however, only a limited number of high-quality, relevant proposals have been submitted, and the system for announcing NASA's needs for ground-based investigations in the behavioral sciences apparently needs modification to assure that specific research requirements couched in appropriate scientific language reach the intended target audience.

The stated objectives of NASA's research program in the psychological aspects of manned space flight are to: (1) increase the data base, where needed, concerning human psychological response to specific stresses related to the space station environment and operation; (2) develop methods for identification of individual susceptibility to such stresses and for nonintrusive measurement and prediction of psychological problems and associated

performance decrements in the mission environment; and (3) develop preventive and remedial countermeasures for breakdown in psychological health leading to performance decrement. An associated objective is to develop a model relating stress, psychological well-being, and task performance.

1. Description of Tasks

Currently, the program consists of the following five tasks:

Task 199-22-62-01, short title: Cognitive Performance and Stress. The objectives are to explore the nature of cognitive performance in fearful situations, to determine relationships of fear-modified performance to other indicants of fear as assessed in both actual stress situations and in imagination or anticipation of expected stress. The experiments are designed to evaluate behavioral avoidance and psychophysiological responses of subjects in a confinement stress, under both high- and low-demand conditions to tolerate the stressor; to evaluate performance on reasoning, computational, and psychomotor tests while subjects are under confinement stress; to assess the effects on cognitive performance of a confinement stress reduction contingency; to evaluate confinement fear behavior in subjects high and low on the trait of sensation seeking. Attempts will be made to develop predictors to discriminate those persons in whom performance decrements will most probably be observed as compared with those who will maintain or even enhance performance.

Task 199-22-62-02, short title: Determinants of Performance. The objective of this task is the development of techniques for the selection and training of spacecrews and the composition and management of crews in future space missions such as the space station. The focus is on techniques of maximizing performance and adjustment. A broad issue of concern is how best to organize missions with multiple scientific and operational goals and how to develop the kind of cooperative collaboration necessary for effective performance in an interdependent environment. The investigations include the construct validity of psychometric tests of a number of subtle attributes of normal personality functioning. Some of the tests are directly applicable to crew selection as they decompose such dimensions as masculinity-femininity, self-esteem, and need achievement into components which, in a proper pattern, appear capable of predicting high levels of performance and adjustment under conditions of prolonged social intimacy within a continuously isolated group.

Task 199-22-62-03, short title: Small Group Behavioral Interactions. This task explores the performance capabilities of dyads and triads studied in a programmed environment under aversive or appetitive procedural rules for periods lasting up to 28 d. Observed variables include "pacing", social interactions, change of social structure, positive and negative motivation, and group cohesiveness. The experimental facility provides quantitative data on such parameters as stimulus input, behavioral output, location in the facility, activity, interactions, and the effects of cooperative or non-cooperative social contingencies.

Task 199-22-64-01, short title: Human Performance Analysis Methodology. The long-term objective is to develop noninvasive methods of measuring the effects of weightlessness, mental workloads, and environmental hazards of space flight on human cognitive and perceptual processes. Near-term objectives are to determine the physiological basis for evoked magnetic field and evoked electric potential responses and to develop instrumentation and methods for using evoked responses for assessment of human performance in the space program.

Task 199-11-67-01, short title: Physiological Program Planning Analysis. A part of this task is the review and analysis of NASA's research and development needs in the psychological aspects of space flight. It is the subtask for providing NASA with a scientific report of the LSRO/FASEB ad hoc Working Group on Behavior and Performance.

2. Comments of the Working Group

The members of the ad hoc Working Group did not reach a full consensus on the relevance to NASA's needs of the research tasks outlined on pages 34, 35. Some members were reluctant to express an opinion because they considered their familiarity with the research tasks to be inadequate for the purpose. Consequently, the evaluative comments following on pages 35-37 represent a majority, not a unanimous opinion. In all cases, the scientific qualifications of the principal investigators were recognized as outstanding, and the quality of research was judged to be high.

Some members of the Working Group questioned the relevance, in terms of NASA's operational needs, of Task 199-22-62-01, Cognitive Performance and Stress, and recommended reorientation toward more nearly specific space flight questions. For instance, how should NASA plan to recognize, prepare for, and handle an inflight, nonpsychotic panic reaction? How should NASA identify susceptible members of flight crews and prepare them to control

anxieties associated with perceived hazards of space missions? What sort of procedures should NASA consider for coping with other emotional responses to space flight? How should NASA monitor the inflight emotional status of spacecrew members by means of currently available knowledge and technology? Other members thought that the broader orientation represented in the future plans for this task would probably yield useful data applicable to NASA needs.

Task 199-22-64-01, Human Performance Analysis Methodology, reflects exceptional scientific and technical merit and long-term probability of advancing knowledge of central psychophysiological processes and achieving means for their objective measurement. However, while agreeing with the objectives of the task, the research approaches, and the need for continuation of the task, some members of the Working Group questioned whether it should be a part of the NASA Psychology research program, suggesting that it should probably be carried in a NASA RTOP more closely related to neurophysiology.

Tasks 199-22-62-02 and 199-22-62-03, respectively entitled Determinants of Performance and Small Group Behavioral Interactions, were both considered relevant to NASA needs provided that the obtained data will be put to practical use by NASA in such pertinent areas as crew selection, composition, training, and rotation, as well as allocation of responsibility and tasks, role-sharing, and provision of psychological support. Here again, some members of the Working Group believed that the results to be expected from the two tasks might be more relevant to NASA's needs if specific questions were addressed to the principal investigators. Examples of questions that might be appropriate are: (1) Can you produce some data within the next 12 or 18 mo on items that could be used in design criteria for the space station such as the value, for psychological support and quality of life, of a shower, privacy, minimum acceptable living space, and other factors that enrich the habitability of the station? (2) Is there a temporal limit for maintaining optimum psychophysiological homeostasis in long space flights such as 15, 20, or 30 d? (3) How much autonomy should the space station crew be given? How much flexibility in how they accomplish their duties? (4) What are the motivational and productivity values of intimate involvement of spacecrew numbers in such program activities as planning and development of mission requirements, job assignments, workloads, work schedules, and habitability factors? (5) What kind of intrinsic rewards will be the most meaningful for maintaining motivation in the 90-d mission? What are the associated personality profiles? Is it feasible to train people to recognize and profit by their perceptions of intrinsic rewards?

The latter two tasks appear to be somewhat complementary in that one represents a controlled laboratory environment, the other more nearly the situations in the "real world". Therefore, the principal investigators should be encouraged to exchange

information at regular intervals and collaborate, where possible, in formulating extensions of their investigations; that is, information developed in one laboratory may suggest additional hypotheses and experimental variables that could profitably be investigated in the other laboratory or on a collaborative basis.

The psychology research program may be expected to grow moderately under the current system of unsolicited proposals. Nevertheless, the current level of effort is too restricted to produce the research needed to meet the stated objectives of the program. In addition, the scope of the stated program objectives, while broad, appears too restricted to include such essential considerations as the psychological aspects of groundcrew organization, operation, and interaction with spacecrews, and development of improved psychological selection and training criteria and techniques, all of which have significant implications in terms of systems effectiveness and psychological well-being. Accordingly, the ad hoc Working Group has listed some additional research suggestions on these topics in Section V.

V. SUGGESTIONS FOR RESEARCH AND PROGRAM PLANNING

NASA has the opportunity to develop a broad program directed at the psychological, psychosocial, and psychophysiological aspects of long-term space flight, a program directed specifically at optimizing behavior and performance in the space station, or both. The ad hoc Working Group believes NASA should have two programs: a first priority program directed toward the needs of the Space Transportation System and the space station in the near term, using available data, and short-term research to obtain best estimate solutions for the initial missions; and a supporting, longer-term program seeking more optimal solutions and addressing longer-term problems. The shorter-term program should represent a cooperative undertaking of applicable parts of NASA's Human Factors program and research under the Psychology RTOP and should be an engineering design-oriented activity, not a peripheral research and consulting activity. It should be directed at the design of, or at least the requirements for, a space station interior, crew systems, crew operational procedures and tasks, and the specification of crew skills, characteristics, composition, and training requirements.

The longer-term program should explore topics in psychology and psychophysiology such as those identified in Section IV A and B which require a substantial time commitment. Suggestions for both near- and long-term consideration are detailed on pages 40-50.

In submitting its suggestions for research and program planning, the LSRO ad hoc Working Group on Behavior and Performance took into account several factors that have apparently influenced the status of NASA's research, development, and operational support in the behavioral sciences: (1) the admirable history of nearly unqualified success in the manned space programs; available knowledge in human behavior and performance was apparently considered adequate for agency needs, and the astronauts were able to meet the workloads, performance requirements, and timelines almost without exception; (2) the independence that has been accorded the astronaut group in the past in deciding the nature and level of ground-based and flight research and test in which they would participate; and (3) the history of a relatively modest level of effort in NASA in-house and extramural research in the behavioral sciences except for recognizable work in human factors applied to aeronautics.

In addition, the Working Group considered the research implications of the fundamental changes in size, functions, responsibilities, and composition of spacecrews and ground support staffs that have occurred in the Space Transportation System-Shuttle Program and that are contemplated in the space station, the nominal 90-d missions with possible extensions, the emphasis on system productivity which permeates space station planning, and

the changing character of NASA careers for the associated space and ground personnel.

A common theme in the recommendations of expert groups that have advised NASA on research needs in behavior and performance has been the overriding importance of establishing a firm commitment to a well integrated, comprehensive, long-range research and development program. Lacking these critical elements, an otherwise well-conceived program would languish. The Working Group believes that a management strategy should be formulated that will provide for regular, joint participation of behavioral scientists with operational and planning personnel in determining short- and long-term research and development needs, integrating the approaches in the key operational activities of NASA, and applying and evaluating the results.

Various schemes of program planning would serve to assure comprehensive coverage. Examples range from simple checklists of identified specific problems of behavior and performance related to space flight and lists of behavioral elements in a mission-defined matrix of tasks and task components to sophisticated computerized, on-line, interactive data manager systems. One recognized method of planning large research programs in the psychological and social sciences is the ecological systems approach espoused by some members of the ad hoc Working Group (Barker, 1968; Sells and Gunderson, 1972; Wicker, 1979). Such an approach favors a methodology for descriptive analysis of natural settings and social interactions observed unobtrusively. Table 4 is a rough outline of a possible ecological systems schema. The members of the Working Group recognize that studies based on observational methods of operational activities such as space flights are hampered in some ways by numerous uncontrolled variables and that precise measurement of certain important behavioral characteristics requires a finely controlled laboratory setting. Nevertheless, the importance of acquiring behavioral and social data from the real world of NASA training, simulations, and actual space flights cannot be overemphasized.

The suggestions are divided into two main groups:
(1) near- and long-term research and development and (2) technical and other considerations.

A. NEAR- AND LONG-TERM RESEARCH AND DEVELOPMENT

Near term is defined here as research and development whose results are expected within one to two years. The overall objective of a near-term program should be the development and execution of a plan of research in human behavior and performance that emphasizes areas of immediate importance to those in NASA who are responsible for systems planning and development and for mission planning and execution.

Table 4. Schema for an Ecological Systems Approach to Investigation of Psychological and Social Issues in Manned Space Flight

A. Major Systems of Interest

Elements and Issues

Individual:	physiological, perceptual, cognitive, affective, and emotional responses
Social/Interpersonal:	relationship formation, conflict management, absorption of new people, cliques, autonomy
Socio/Cultural:	families, ground control establishment, authority structure, careers, incentives
Interactions Among Systems:	most of the above

B. Approaches

Study change, process, and dynamic qualities by continual monitoring of physiological, psychological, and social responses to participation in space careers. Study all phases, not just training and missions:

<u>Phase</u>	<u>Physiological</u>	<u>Psychological</u>	<u>Social</u>
Baseline	EFFECTS	PROBLEMS	SOLUTIONS
Training			
Mission			
Postmission			
Long-term			

Use a spectrum of methods: quantitative, qualitative experimental, observational, self-reports, case methods, archival methods, and expert reviews.

1. Performance Assessment

Selection, construction, and validation of a new generation performance battery for use in training, in mission simulations, onboard the space station, and, if possible, on some future Shuttle missions should be planned and scheduled.

Embedded secondary tasks should be selected and designed for incorporation with existing Shuttle communications and control equipment and for the space station as a part of an evolving performance assessment and monitoring capability (see page 27).

The feasibility of using available onboard video and audio capabilities of the Shuttle should be determined and plans made for such use in assessing and monitoring crew performance (see also page 29).

Development of methods of objective measurement of psychophysiological status of human operators should be continued along recognized lines, and periodic expert reviews of this subject should be scheduled. Correlations among evoked cortical potentials, other measureable phenomena of the central nervous system, and perceptual and perceptual-motor activities should be sought.

Simulation of the space station system represents one useful approach to evaluating behavior and performance. A basic resource for this will be the Space Station Mockup Research Facility planned for NASA's Ames Research Center. This facility should lend itself to evaluation of behavior and performance of individual members and partial or complete space- and groundcrews operating in unison in selected segments of proposed missions. Valuable data should be obtainable in important areas including: (1) physical and mental limitations of individual and crew adaptability and performance; (2) methods of monitoring and measuring individual and crew performance; (3) crew interactions and group dynamics; (4) productivity and psychological well-being as influenced by design of work, living, and recreation areas and other habitability factors.

Both near- and long-term support is needed for basic laboratory studies to help advance theory in the area of performance and its measurement.

2. Expert Concept and Position Papers

Consideration should be given to investing in a series of special literature reviews and analyses by appropriate experts as a method of focusing available knowledge and producing concept or position papers on practical issues in behavior and performance. Reviews of this sort would, in addition, identify

missing knowledge and would help to refine research needs. Members of the LSRO ad hoc Working Group represent informed sources of names for such endeavors. Suggested topics include the following; they are listed without reference to priority:

- (1) best methods of molding attitudes and maintaining motivation to achieve optimum long-term performance; what would motivate people to go on long, routine, commercial space missions?
- (2) the reversibility or irreversibility of adverse adaptive biomedical responses to space flight and their predictable psychophysiological, psychological, and social consequences; this is potentially important from the standpoint of the health, well-being, and effectiveness of spacecrew personnel as well as public liability for alleged or real permanent damage;
- (3) types and variations of personality that are best suited for coping with the stresses of long-term space flight including crisis incidents;
- (4) the formation of "in-groups" and "out-groups" and means of preventing or controlling untoward results, such as special training and establishing cooperative bonds between individual spacecrew and groundcrew members;
- (5) the advantages and disadvantages of crew participation in deciding issues such as autonomy of the spacecrew, certain inflight procedures, space station design features, equipment, and flight clothing, development and use of performance assessment and monitoring, and the acceptability of proposed tasks in the mission objectives; a substantial amount of untapped information is available in the area of worker participation;
- (6) the utility of non-vocal communication as a means of improving inflight crew interaction and preflight training;
- (7) individual and group methods of coping with stress for application inflight as well as pre-and post-flight;
- (8) expert performance and protocol analysis as a means of extracting effective procedural strategies for use in training, performance assessment, and robotics;

- (9) experiences in military and experimental aeronautics on methods of eliminating or dealing with illusions of flight, spatial disorientation and problems of time compression; an example is preventing the "floating instruments" illusion by increasing the contrast between figure (instrument) and ground;
- (10) time estimation as an approach to understanding the phenomenon of time compression that has been noted during Shuttle landing approaches and alterations of time perception during space flight; there is a large literature on time estimation;
- (11) the formation of relationships in isolated environments and the problem of contact control to determine whether a significant potential problem exists for the space station and to identify needed research; a useful but limited literature exists in this area;
- (12) techniques of intervention in emotional crises that are suitable for use in space missions;
- (13) means of providing psychological support during long missions;
- (14) work/rest cycles; during long missions, how many days per wk should spacecrew members work and at what fraction of their maximum work capacity? Is the 70% of work capacity industrial rule applicable to space flight?

3. Small Group Dynamics

Issues in group dynamics are reviewed on pages 24, 25. Key areas needing additional work include: (1) definition of the components of individual and group motivation and their impact on behavior of space- and groundcrews; (2) the effects of heterogeneity of crews (astronaut/nonastronaut, mixed genders, different cultural backgrounds, different levels of responsibility, etc.) on behavioral and social interaction and productivity; (3) development of training methodology for social sensitivity, intracrew and space-ground communication, cooperation, and coordination in normal and emergency operational conditions; (4) organization for optimal productivity, including leadership, command and control, role sharing, crew participation in mission planning and decisions; and (5) best methods for crew rotation in the space station.

Analysis of available data in the foregoing subjects may be facilitated via concept and position papers produced as suggested on page 42. In addition, NASA should request its scientific investigators who are working on small group dynamics to provide their best estimates on issues listed in the preceding paragraph and to address others as they relate to space station planning. Examples are: (1) crew composition in terms of personality characteristics; (2) factors abetting successful partial rotation of crews; (3) prediction of duration of optimal productivity; (4) optimal organization of spacecrews for cohesiveness and cooperation; and (5) methods of controlling excessive "in-group" autonomy and preserving space-ground cooperation.

Basic studies of the interactions of individual personality factors and group performance should be accorded a high priority. Effort should focus on personality characteristics that favor compatibility and cohesiveness of small groups and should emphasize the real world of the physical and operational environment of the space station. In addition, the effects of group training in modulating individual personality characteristics toward improving group cohesiveness and productivity should be investigated.

Research on the psychological aspects of selection criteria for demanding environments should emphasize specification, measurement, and validation of personality traits associated with superior individual and group effectiveness and adaptability as influenced by the operational environment (Helmreich, 1984). Further investigation of the components of achievement motivation and their separate or interactive effects on the types of behavior that are desirable for successful participation in a space station crew would probably yield improvements in selection criteria.

4. Perceptual, Cognitive, and Motor Effects

More nearly precise inflight evaluations than were heretofore feasible, of the possible effects of space flight on the sensory systems should be planned for both the near and long terms including exploitation of opportunities in the Shuttle missions. The coverage should be comprehensive: the special senses and a selection of somatic senses including touch, pain, heat, cold, and kinesthetic. The relative priority of such evaluations is low except for those related to the sensory systems putatively involved in space sickness and possible alterations in olfaction and gustation as they may relate to the acceptability of food, water, and breathing mixtures.

Acquisition and evaluation of inflight data on all space-related perceptual phenomena not considered operationally acceptable should be a continuing process of relatively high priority.

Such phenomena include visual and other sensory illusions, spatial disorientation, "reentry vertigo", disturbed time sense, and "time compression".

The question whether an operationally significant functional degradation accompanies the skeletal muscle atrophy in long space flight should be addressed. For instance, is there an impairment of neuromuscular control that affects smooth control performance and fine movements of the hands and fingers? Is there excessive intention tremor? This is a question of both near- and long-term interest.

A question of great interest is whether Shuttle flights impair psychomotor fine tuning in the pilots so that they tend to over- or under-control in critical phases of flight. If operational analyses suggest that a problem exists, postflight simulator tests might offer a useful approach for performance assessment. An associated subject is the absence of customary perceptual-motor linkages in weightlessness and identification of possible short- and long-term behavioral consequences. Both animal and human studies should be considered, including long-term follow-up of spacecrew personnel.

Investigations of the effects of simulated space station missions on perception, cognition, and psychomotor performance should be planned for both the near and long terms. Planning should take advantage where possible of integrating studies with other planned experimental (Ames Research Center) and training (Johnson Space Center) simulations. Where feasible, the studies should include observations and tests of skill maintenance, work-rest patterns, task allocation, group processes, and the behavioral effects of monotony of environmental stimulation.

The data base on complex perceptual and cognitive skills needs major augmentation in order to improve matching the human operator and the machine, man-system reliability, and capabilities for supervisory control of space systems. Basic research needs in these areas are identified in Pew (1983). Examples of research that should be supported are: (1) theories of human inference and associated cognitive models (Collins and Loftus, 1975; Newell and Simon, 1972); (2) theories and definition of the concept of human error (Sheridan et al., 1983); (3) refining the concept of mental workload (Sheridan et al., 1983); (4) determining operator capabilities and limitations for sustained, long-duration, mental workloads with fluctuating levels of demand (Boff et al., 1985); (5) defining psychophysiological correlates of mental workload (Boff et al., 1985); (6) the definition, separability, and coordination of cognitive systems and subsystems (Kinsbourne and Hicks, 1978; Navon and Gopher, 1979; Posner, 1978); (7) self-regulation of behavior in stressful situations (Sheridan et al., 1983); and (8) relations among cognitive processes, stress, and emotional responses (Bower, 1981; Posner and Rothbart, 1980).

5. Psychosocial Considerations

Items that should be considered in planning, in addition to those already mentioned in connection with group interactions may be addressed using an "ecological systems" approach such as is outlined on page 40. More work is needed in the near term on conflict management, crisis intervention, psychological support, absorption of new people into formed groups, and the question of optimal authority structure in spacecrews and ground control groups. The data base on person-environment linkages is adequate in a number of areas such as spatial attachment, appropriation, and territorial control (Altman, 1975; Stokols and Altman, 1985), but more work is needed on privacy needs and methods of meeting them in confined environments (Bluth and McNeal, 1981).

Another useful approach could be based on a confidential survey of the experiences and career expectations of NASA's mission and payload specialists in the STS-Shuttle Program, focusing on attitudes regarding the importance of their work, effects on their professional growth, effects of separation from families, incentives, and long-term career opportunities and commitments (Helmreich, 1984). Knowledge for understanding and dealing with psychosocial problems in various social systems is available (for instance, see Deaux and Wrightsman, 1983).

Unobtrusive expert observation of space- and groundcrews during training and space operations offers opportunities for acquiring valuable data and descriptive analyses on behavior, performance, and social interactions. Direct observations and/or observation via video and audio monitors are primary means. During space flight, attention should be given not only to operator performance and communications, but also to ordinary activities of onboard living such as hygiene, eating, leisure, sleeping, and routine station maintenance. Methods for using data acquired in this manner are discussed on page 49.

6. Methodology and Models

A high priority should be accorded the development and operational employment of improved, noninvasive methods of monitoring indicators of psychophysiological status, estimating task workloads, and observing and assessing crew performance. Proposed developments and operational tests should be planned in coordination with appropriate NASA operational personnel including flight crews and, where pertinent, the operational medical support staff. Participation of both flight- and groundcrew personnel in planning and testing devices and techniques should be sought, the underlying objective being improvement in operational proficiency and flight safety.

Methods of stress-response analysis that have proved to be practical in field situations include voice analysis, measures of intention tremor, respiratory rate and pattern, blood pressure, and observation by behavioral scientists via video or sequential photography. Voice analysis has been used for assessing stress response in space flight (Simonov, 1975; Simonov et al., 1980), experimental and operational diving, and in a variety of other stressful situations (Hollien, 1980).

Plans should be made to integrate voice analysis as a means of psychophysiological monitoring during space station mission simulations for ultimate use in flight. Moreover, additional studies of the effects of mental and physical stress and combinations of these on voice characteristics should be done to improve theory and advance the state-of-the-art.

Devices to measure intention tremor have been developed for laboratory and field use. It may be feasible to embed such devices in operator-controlled equipment so as to provide unobtrusive data. Use of such embedded equipment should be with the knowledge and consent of the operator. Methods for measuring intention tremor are described in such representative reports as: Bachrach and Bennett (1973), Bachrach et al. (1971), Tresansky (1973), and Spencer et al. (1979). By means of current microprocessor technology, the strain gauge devices treated in the foregoing references could be improved or replaced.

For measuring workloads in various operator tasks including in flight use, the embedded secondary task methods should be considered (see page 27). Further development of such techniques should lead to practical methods of performance assessment featuring only trivial additions to procedures to be performed in simulation and in flight. Additional information on this methodology is available from the Workload and Ergonomics Branch (HEG), Human Engineering Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433. Successful employment of such methods will require knowledge, consent, and cooperation of the tested personnel. Here again, the ultimate objective is improvement in individual operator proficiency, better equipment design and layout, more efficient task allocation, and crew productivity.

Performance assessment should include behavioral type performance measurement of complex perceptual motor activities and cognitive functions. Currently, the best, most comprehensive assembly for such use is the tri-service performance assessment battery whose development is nearing completion. It is designed to meet the requirements for laboratory and field use in the military departments, and represents an attempt to combine the best features of several existing devices including the Army Performance Assessment Battery (Thorne et al., 1983), several Navy batteries, and the Air Force Criterion Task Set (Shingledecker,

1984). Plans should be made for testing pre- and postflight performance of members of STS-Shuttle crews using this kind of sophisticated equipment. Moreover, space station planning should consider the need for onboard performance assessment as a means of monitoring the psychophysiological condition of the crew and for research. The feasibility of adapting the tri-service performance assessment battery for inflight use should be addressed.

An emerging technology of potential value in assessing and monitoring perceptual processes is measurement of central nervous system transmission times. This can be done precisely in the visual and auditory systems via recording of steady state visual evoked responses and brainstem auditory responses. For example, variables such as perceived workload alter the temporal patterns of the responses. This methodology should be considered as another promising approach to the objective measurement of central nervous system processes (Donchin, 1984; Hatanen, 1982).

NASA should make use of techniques for unobtrusive, noninterference collection methodology to study on-going activities inflight. Expert behavioral observations via onboard video and audio space-ground links would provide data in important areas such as operator performance, functional difficulty associated with weightlessness, onboard communication, social interactions, and changing qualities of individuals and the group as they unfold during a mission. Proven techniques exist for qualitative and quantitative analysis of unobtrusive data (Barker, 1968; Helmreich, 1972; LeFan and Helmreich, 1971; Radloff and Helmreich, 1968; Radloff and Mach, 1970; Wicker, 1979). Agreement should be arranged among investigators and operational personnel including mission participants regarding access to monitoring and the confidentiality and release of data on the behavior and performance of individuals.

Special types of training appear promising for the flight- and groundcrews of the space station. These include "social sensitivity", "team building", cohesiveness and interpersonal communication training, and strategies for coping with the stresses of space station occupancy such as relaxation techniques. Methods for accomplishing and evaluating these special types of training need improvement to establish their potential for the space station program.

A useful process in past space system planning was the "walk/talk through" with management and planning personnel, focusing on such features as interior design and habitability, system performance requirements including ground and spacecrew performance, and crew composition. Such a procedure helps to identify specific unresolved problems and to organize required decisions which specialists in various disciplines of psychology and human factors could then review relative to available data in order to

determine short- and long-term research needs and suggest priorities. Some such method of organizing and prioritizing research needs and defining in detail the nature of problems to be solved, based on specific decisions that must be made by space station planners and designers would help to sharpen the validity of some research needs and downgrade the importance of others.

Various methods of self-reporting should be used as components of behavioral evaluation schemes. Examples include attitude (Miller et al., 1967), emotional state (Helmreich, 1971c), mood (LeFan and Helmreich, 1971), personality assessment (Symonds, 1931), and Subjective Workload Assessment Technique (Reid et al., 1981). Other pertinent references in this area include: Anastasia (1969), Endler and Okada (1975), Gough (1960), and Rotter (1966).

A plan should be formulated for noninvasive tracking of neurohormonal markers of responses to stress. Biochemical markers exist that reflect the magnitude of perceived stress and suggest the direction of coping behavior. For example, effective coping leads to a decrease in pituitary-adrenal response to stress independently of adrenal corticosteroid negative feedback. Development of means to determine the point of impending failure of the adaptation response to long-term build up of stresses preceding and during a major space mission would have obvious value as an operational monitoring technique and for research. Candidate markers include urinary cortisol, testosterone, and catecholamines (Elias, 1981; Emurian et al., 1981; Scaramella and Brown, 1978).

Optimal cognitive strategies should be developed to improve training methods. Experience in the area of expert performance suggests that extraction of performance strategies from experts can provide useful data for improving training. Expert performance information may be obtained by protocol analysis or by experimental procedures (Hayes, 1982).

In view of the diminution of the extrinsic rewards that characterize the earlier, pioneering manned space programs, certain psychological characteristics will assume increasing importance as determinants of success of spacecrew members on long missions; for example, intrinsic motivation to master a skill and do it well as a basis for job satisfaction. Defining, organizing, and assigning tasks and responsibilities, role-sharing, and leaving room for some flexibility and creativity in modifying prescribed space station activities are some of the elements for consideration as enhancers of intrinsic rewards.

Provisions should be made for the inclusion of physiological and metabolic data with other data in evaluating behavior and performance. Such data would normally include heart and respiration rates, blood pressure, oxygen uptake and carbon dioxide output, obtained by well-established space biomedical technology.

B. TECHNICAL AND OTHER CONSIDERATIONS

The results of comprehensive, detailed space station analyses in areas affecting tasks and performance requirements of space- and groundcrews are needed at their earliest availability by NASA research program planners for determining specific research needs in behavior and performance. Such information should include not only the tasks, performance requirements, and timelines, but also station architecture, layouts, placement of consoles, displays, and controls, characteristics of work stations, space allocation, and related items.

The Working Group recognizes also that the planning and design studies for the space station will include input for interior design requirements, habitability, crew systems, tasks, operational procedures, timelines, and specifications for crew skills, composition, and other characteristics. Questions or uncertainties arising from lack of data during space station planning and design studies should lead to identification of critical short-term research needs as well as problems requiring long-term investigation. The singular importance of prompt development of, at least, provisional space station mission scenarios, systems requirements and functions, and task analyses was stressed by the Working Group.

Consideration should be given to widening the scope of selection procedures to evaluate such characteristics as: (1) ability to cooperate and work productively with flight crew peers and ground support staff for extended periods under the influence of the imposed environmental stresses; (2) social skills such as the ability to provide and receive social support; (3) tolerance for acute, life-threatening stress and for life-threatening stress extended in time; (4) routine, day-to-day productivity pre-flight, inflight, and postflight; (5) public image.

A psychiatric evaluation should be incorporated with the annual medical examination of operational space and ground personnel as a routine part of the periodic evaluation.

Special behavioral training to prepare individual members and whole flight crews for space station missions should be formulated on the basis of currently available information. Teachable components to be considered include psychological self-defense, psychological coping strategies, and principles of interpersonal compatibility such as awareness of each others' needs. Teaching in coping skills should be aimed not only toward controlling the effects of inflight stresses but also day-to-day pre- and post-flight stresses of an inter- and intrapersonal nature.

Medical contingency planning will, no doubt, include preparation for managing incidents or abnormal psychological reactions inflight including "worst case" situations such as

severe panic or a frank psychotic break. It is quite possible for psychosis to develop on an organic basis which was too subtle to be identified during normal medical evaluation; for example, a parathyroid or adrenal tumor. Moreover, aggravated degrees of physiological responses to space flight, such as electrolyte and hormonal imbalances, could lead to psychological impairment. The possible need to control and sustain a mentally incapacitated crew member for several weeks aloft should be addressed in terms of diagnosis, treatment, equipment, and preflight crew training.

Three problems that deserve high priority for prompt action are: (1) the lack of a secure radio link for private space-ground communication; (2) the absence of a plan for monitoring and assessing crew performance during training, simulations, and inflight; and (3) lack of clear definition of the operational significance of "reentry vertigo" and "time compression." The Working Group endorses private communications as a prominent factor for morale and quality of life, especially in long missions. Assessment of performance of actual crew members in the real world of NASA preflight training, mission simulation, and space flight with a view toward optimizing performance, training, and design of workplaces, equipment, and controls is considered a top priority action item. Some feasible technical approaches are outlined in Section IV B.

Planning should begin as soon as possible to incorporate performance assessment into the Shuttle and space station programs to provide for continuous unobtrusive monitoring of sensory, cognitive, and motor performance and psychophysiological indices employing currently available means (e.g., video and audio monitoring, ECG, blood pressure, and respiration), pre- and postflight testing using state-of-the-art performance assessment batteries (see page 28), and embedded secondary task techniques (see page 27).

Informal reports of disorientation during orbital insertion and reentry, time compression, and possible tendencies toward inappropriate control inputs in the Shuttle Orbiter suggest a need for investigation beyond what has occurred to date. It is understood that NASA has solved the time compression problem by operational means; however, the dimensions and significance of these experiences are not clear to the Working Group. In view of their apparent relationship to operational safety, extraordinary effort should be directed toward problem definition, resolution, and identification of needed research and analysis including possible inflight expert behavioral observation.

Finally, the ad hoc Group believes that a majority of recommendations for investigations in the behavioral sciences that are referred to in Section III C are still applicable to NASA's near- and long-term research needs.

C. PRIORITIES

It is suggested that NASA consider the suggestions for research and other actions that are detailed in Section V, A and B in order of priority similar to that shown in the following outline.

1. Near- and Long-term Needs

a. Near-term

- Develop a new generation performance assessment battery for use in training, mission simulations, and flight. A suggested model is the Tri-service Performance Assessment Battery.
- Develop appropriate embedded secondary tasks as means of monitoring and assessing workloads and performance in space missions.
- Plan the use of Shuttle onboard video and audio resources for behavioral observation of crews.
- Provide near- and long-term support for basic laboratory studies to improve theory of performance and its measurement.
- Plan studies of behavior and performance to take advantage of the Space Station Mockup Research Facility contemplated for Ames Research Center. Include perceptual, cognitive, and psychomotor parameters and group dynamics.
- Plan near- and long-term approaches to investigating and solving crew problems such as conflict management, integration of new members, crisis intervention, psychological support, authority structure, and distribution of responsibilities and work.
- Plan near- and long-term expert behavioral observation of space- and groundcrews during training, simulations, and space flight.
- Investigate interactions of personality factors and group performance.

- Develop methods of noninvasive tracking of neurohumoral markers of responses to stress. Investigate means of determining indices of impending failure of the adaptation response to sustained or intermittent stress.
- Acquire and evaluate inflight data on space related perceptual phenomena with potential or demonstrated operational or psychophysiological significance.
- Study the effects of space flight on the precision of psychomotor functions and control.
- Plan special training for flight- and ground-crews of the space station program including social sensitivity, cohesiveness, interpersonal communication, and strategies for coping with operational stresses.

b. Long-term Research and Development

- Continue investigation and development of methodology and instrumentation for objective measurement of psychophysiological processes, status, and performance. Examples of approaches include:
 1. Improved performance assessment battery
 2. Embedded secondary tasks
 3. Central nervous system transmission times
 4. Intention tremor
 5. Evoked cortical electric potentials and magnetic field responses
 6. Voice analysis
 7. Analysis of video recordings and sequential photographs
- Support basic studies of perceptual and cognitive processes to improve man-machine matching, man-system reliability, and human supervisory control of space systems.
- Continue to develop methodology and plans for expert, unobtrusive behavioral observation of the activities of space- and groundcrews.

- Improve methodology for qualitative and quantitative analysis of unobtrusively obtained behavioral data.
- Plan additional studies of factors that influence group dynamics such as motivation, heterogeneity of crews, organization for optimal productivity and psychological stability; and special training for social sensitivity, crew cohesiveness, and coping strategies.
- Investigate methods of enhancing intrinsic rewards for future spacecrew personnel including space station crews.
- Conduct studies to improve the data base on spatial attachment, appropriation, territorial control, and privacy needs as may be related to space station crews.
- Develop optimal cognitive strategies to improve training methods. One useful approach involves extraction of performance strategies from expert operators by protocol analysis.
- Plan investigations of the effects of space flight on perceptual, cognitive, and motor capabilities and limitations. Include pertinent sensory systems.
- Plan long-term follow-up studies of behavioral and psychomotor changes that might result from the absence of normal perceptual-motor linkages in weightlessness.
- Include physiological and metabolic data in developing methods of evaluating behavior and performance.

2. Technical and Other Considerations

- Plan for monitoring and measurement of performance of operational personnel during training, mission simulations, and actual space missions. Expedite coordination of this with all appropriate NASA activities.
- Select and implement procurement of expert concept and position papers.

- Define clearly the operational significance of psychophysiological phenomena occurring on STS missions.
- Add psychiatric evaluation to the periodic medical evaluations of spacecrew and mission groundcrew.
- Include management of inflight emotional crises and psychotic breaks with medical contingency plans.
- At earliest availability, provide research program managers for RTOP 199-22-62, Psychology, with detailed planning information for the space station such as provisional missions, work to be accomplished, work schedules, workloads, required skills and design concepts for psychological support and quality of life onboard.

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